LASER RANGING ON SPACE DEBRIS WITH THE CHANGCHUN SLR STATION.

LIU Chengzhi[1]. SUN Jiannan[1,2]. DONG Xue[1]. LIANG Zhipeng[1]. FAN Cunbo[1]. SONG Qingli[1]. HAN Xingwei[1]. [1]Changchun Observatory, National Astronomical Observatories, Chinese Academy of Sciences, Changchun, 130117; [2]University of Chinese Academy of Sciences, Beijing, 100049; lcz@cho.ac.cn.

Abstract: The Changchun SLR station has upgraded to track space debris in 2014. The system operates with a 60mJ/10ns/500Hz 532.0nm laser (M^2<1.5) and an optical camera for closed-loop tracking. With this configuration, 466 passes of 224 different space debris targets were obtained during 19 terminator sessions, each about 1.5h. Target distances are between 460 km and 1800 km, with RCS (radar cross sections) from >15 m^2 down to <1.0 m^2. Measured range had an average precision of about 1.0 m RMS. The system can be conveniently operated by one person. The presentation will introduce the technical developments and the observation results obtained. By analyzing the laser range data, range residual of about 1~2 meters is obtained.

Key Words: Space Debris, Laser Ranging, Closed-loop Tracking

Introduction: Changchun station planned to begin the space debris laser ranging at the end of 2013, which was based on Changchun 60cm aperture laser ranging system. Aiming at a series of problems such as space debris objects' angular rate, prediction accuracy and signal identification, we established space debris laser ranging (DLR) system with high repetition rate, high precision, high sensitivity, high automation and realized effective observation at last. Up to now, the DLR system has achieved nearly 466 passes of 224 different space debris targets during 19 terminator sessions each about 1.5h.

DLR system description: DLR system was arranged in parallel in Changchun SLR system, the structure was shown in Fig.1. We used almost the same equipments of SLR system except for a ns-laser. A ns-laser was placed beside ps-laser, switched by a moveable mirror (Fig.2). The moveable mirror could allow ns-laser through or direct the kHz ps-laser (satellite) to the coudé path.

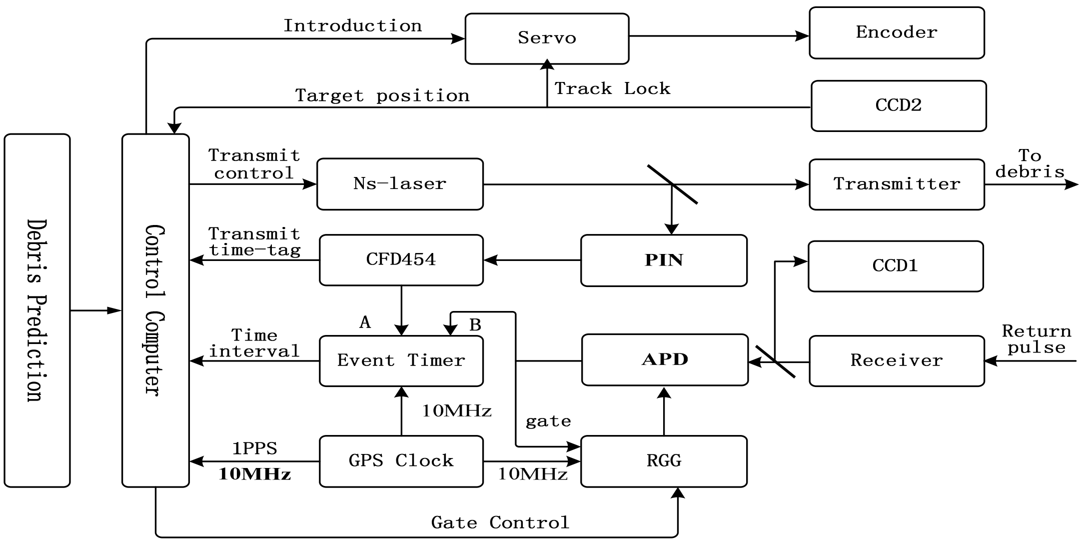


Fig.1 Assembly of DLR System

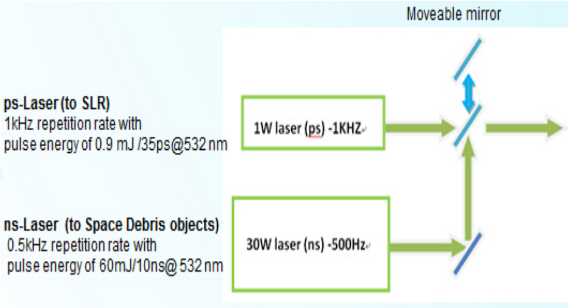
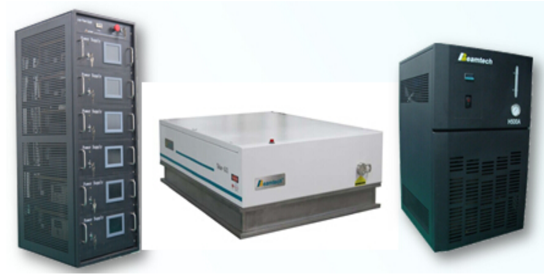


Fig.2 Structure of DLR System



a. Power b. Laser c. Water cooling

Fig.3 Appearance of ns-laser

Software system: In order to get effective data, a serial of operation was done on the DLR software system, such as tracking control system upgrade, data base establishment as the target selection assistant and data identification in tracking to select the effective signal against the huge noise.

ns-Laser: A ns-laser Tolar was used in DLR system as key equipment made by Beamtech Optronics Company, Limited. The Tolar is a Nd:YAG laser operation at 532nm and providing 30W average power at 500Hz. Table 1 shows the main performances of Tolar.

Beam quality and stability are critical requirements for the system delivering the energy efficiently to the target. Automated control software was used to operate the laser, and common maintenance was needed to ensure its performance.

Tab.1 Table of Tolar performances

Performances	**Ns-laser**
Working Mode	LD pump
Wavelength	532nm
Repetition Rate	1-500Hz
Pulse Energy	60mJ/500Hz
M^2 Factor	≤1.5
Pulse Width	9-10ns
Beam Divergence	0.4mrad

Target Selection Assistant: As it is extremely difficult to track objects smaller than 10cm, due to both their small cross section, and also their short passing time, we planned to track the targets with the orbit height of about 1000km, RCS larger than $1m^2$, and easier to track under our own estimate.

Fig.4 Target Selection Assistant Software

Target assistant software was developed, including target estimate, TLE automatic updates and Target selection. The interface of Target Selection Assistant Software was shown in Fig.4. Space debris could be selected by target type, RCS, pass maximum elevation, and rebound index, we could select targets we need and download TLE prediction files onto local computer disk to use. Also, an easily-observe-index was defied to select the debris which may easy to track. This software saved much time for us to select tracking target and also improved detection rate.

Upgrade Tracking Control: The tracking control software was upgraded in 2014.

- ✧ Real-time rebound index calculation to estimate the probability of return pulse.

- ✧ Target Closed-loop with CCD image to ensure the target in the center of view.
- ✧ Laser beam recognition to identify the laser beam so as to adjustment according to the tracking.
- ✧ Laser beam automatic adjustment to automatically adjust the laser beam to the certain position.
- ✧ Automatic TB (time bias) and RB (range bias) correction to automatically correct the TB and RB according to the certain target.

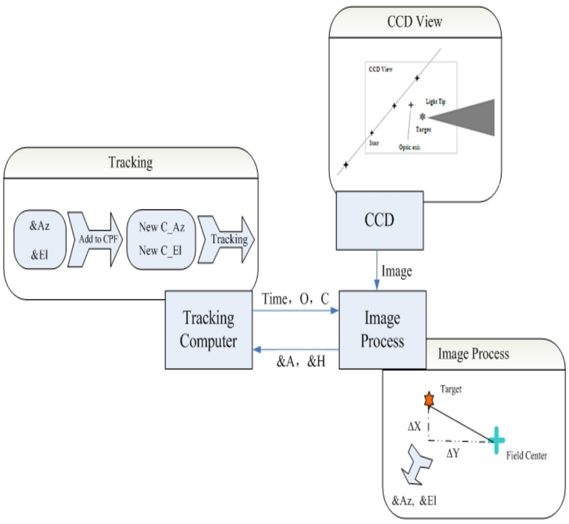


Fig.5 Closed-loop with CCD image

Range bias Improved: As the accuracy of TLE prediction is low (a few hundred meters), it is necessary to improve the predicted orbit accuracy.

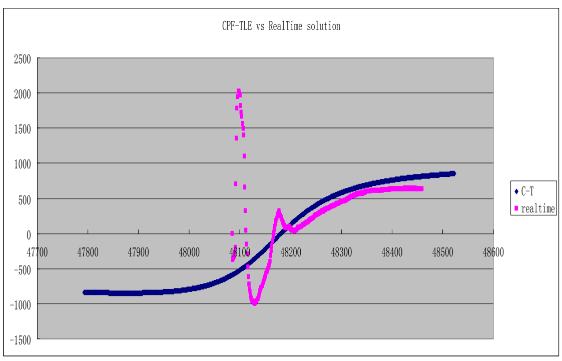


Fig.6 Range bias improved by position bias

We developed a method to calculate the RB bias according to real-time visual position bias, which could improve the prediction accuracy to less than 100m in a few minutes. The results of range bias improvement were shown in Fig.6.

Data Identification in tracking control: Besides effective data, the space laser ranging system received lots of useless noise under high repetition frequency, which made effective data flood in the noise very hard to identify. Even through spatial filter (application of variable aperture), temporal filtering (accurate range gated time) and spectral filter (high through the band-pass filter rate), the data also could not be identified by eyes.

The multiple iteration algorithm was used in software control system to identify effective data, as effective data received by DLR system obeys normal distribution which is different from noise obey random distribution. The range of O-C value could be estimated according to the precision of orbit prediction, which is the basis for effective data identification. Fig. 7 showed the effect of data identification in tracking control software. The data could be clearly seen on the screen.

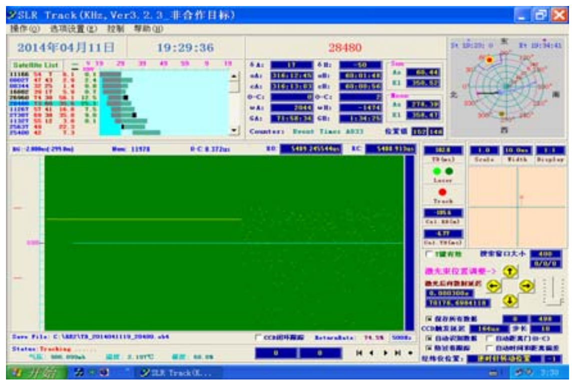


Fig.7 Data Identification in tracking control

Observation Results: During Feb. 18, 2014 and Apr. 30, 2014 we scheduled 18 tracking days and successfully got 466 passes of 224 different targets, with elevation from 19° to 87°, range distance from 450km to 1800km and radar cross sections from >15 m^2 down to <1.0 m^2. Up to 72 passes we got in a single day and even 26 passes was obtained in twilight time during our tracking. For

NORAD 28480 target, we obtained about 60000 points in only 4 minutes, which is amazing compared with other targets tracking (Fig. 8).

Preliminary analysis of laser range data: During the space debris tracking champaign from March to April 2014, several objects were tracked in multiple passes of consecutive days (Tab.3).

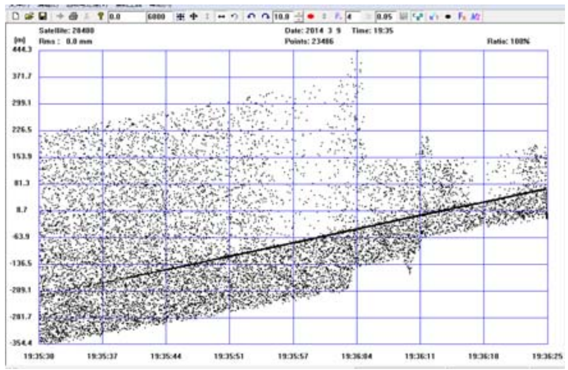


Fig.8 28480 data (without noise delete)

Tab.2 Debris Ranging Data Examples

NORAD	PASS	DATA POINT	MIN RANGE （km）	MAX RANGE （km）	RCS （m^2）
28222	8	17500	658.056	1197.68	11.9
37363	7	8628	556.117	1065.762	5.1
28738	6	14586	646.069	1140.722	12.7
25723	6	5896	524.638	1050.787	4.9
25400	6	5691	830.435	1603.899	11.6
25732	6	2910	815.441	1137.727	6.7
38341	5	3180	722.51	1627.874	18.5
24797	5	3971	632.563	1388.042	10.1
5118	5	2910	593.595	990.821	6.8
24298	5	4332	852.915	1732.805	8.8

Tab.3 Space debris objects with multiple passes of data (from March 1st to April 12th)

NORAD No.	Data Time(UTC)		Length of data(s)	Amount of Points
28222	04-04	20:02:38-20:03:25	47	889
	04-06	19:56:36-19:57:23	47	915
	04-07	19:57:03-19:57:30	27	3477
	04-11	19:47:23-19:47:39	16	2160
	04-12	19:45:51-19:47:08	77	2097
37363	03-01	11:08:47-11:09:41	54	573
	03-02	11:31:06-11:31:49	43	242
	03-06	11:20:25-11:23:45	200	1387
	03-07	11:42:58-11:43:59	61	1499
5118	03-06	11:27:10-11:27:25	15	130
	03-07	11:21:36-11:21:49	13	224
	03-09	21:06:40-21:07:42	62	1077

24298	03-01	11:57:39-11:59:23	104	877
	03-01	20:55:51-20:56:29	38	273
	03-02	11:48:32-11:49:41	69	701

Method of Orbit Determination (OD) : The size of space debris object is ignored, i.e. regarded as a point. In the orbit determination, the following numerical models are used: 1) Earth Gravitation model GGM02C(70×70); 2) N-Body model with ephemeris JPL DE403; 3) Solid tide model conforming IERS conventions 2003; 4) Ocean tide model TOPEX3.0; 5) Earth orientation with IERS EOP series; 6) Solar radiation pressure and albedo pressure; 7) Atmospheric drag model DTM94; 8) Marini-Murray tropospheric delay model;

By using the above models, the orbit determination with laser range data from several objects (28222, 37363, 5118 and 24298) converges. By comparing range measurements and orbits, the range residual in orbit determination is about 1~2 meters (Fig. 9), comparable with laser range measurement RMS (60-80cm).

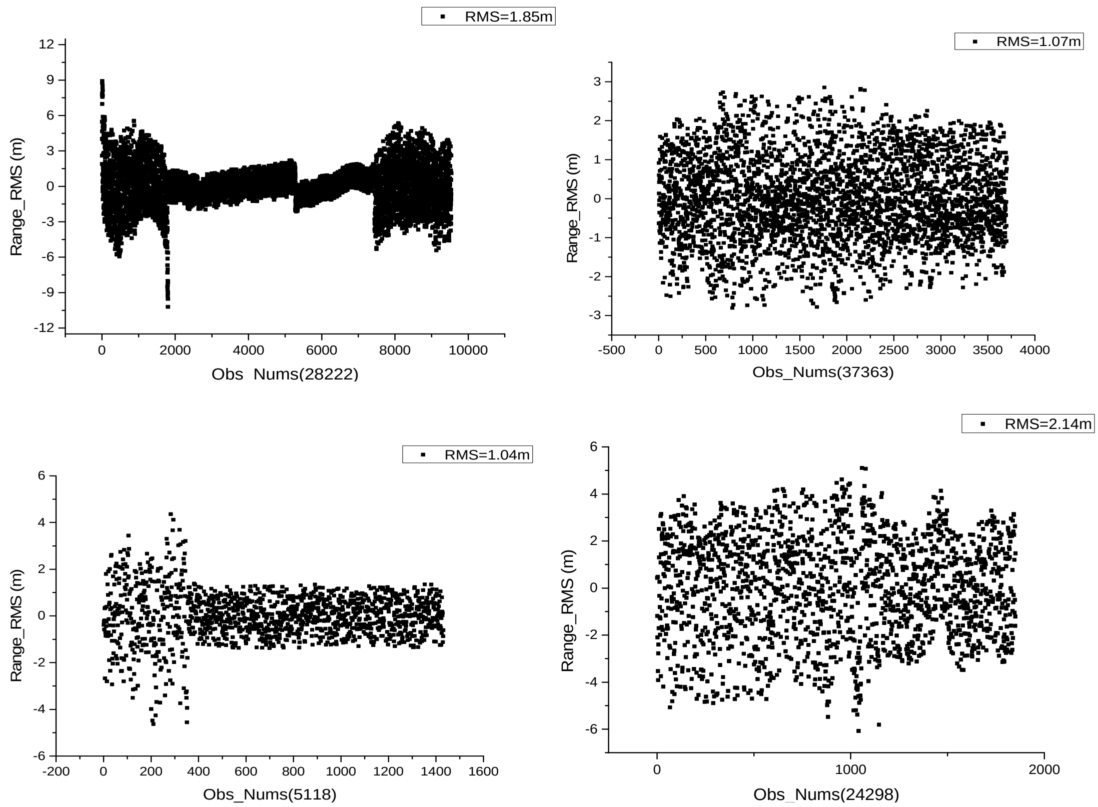


Fig. 9 the range residual of the measurement after OD

Summary: In short, Changchun high rate DLR system has run well since 2014-02-18, and the data is also obtained in twilight, with the elevation lasted from 19° to 87°, distances between 460 km and 1800 km, RCS (radar cross sections) from >15 m^2 down to <1.0 m^2. Now, we are planning the space debris laser ranging on 1m telescope at Changchun station. By analyzing the laser range data, range residual of about 1~2 meters is obtained.

References:

[1] Jizhang Sang and Craig Smith. An Analysis of Observations from EOS Space Debris Tracking System. *http://jzhsang.users.sgg.whu.edu.cn/*

[2] Craig H. Smith. The EOS Space Debris Tracking System. *www.amostech.com/TechnicalPaper*

[3] G. Kirchner, F. Koidl, F. Friederich, et al. Laser measurements to space debris from Graz SLR station. *Advances in Space Research, 2013, 51:21–24*

[4] Ben Greene. Laser Tracking of Space Debris. *http://cddis.gsfc.nasa.gov/lw13/docs/papers/adv_greene_1m.pdf*

[5] G. Kirchner, F. Koidl, F. Friederich, et al. Laser measurements to space debris from Graz SLR station. *Advances in Space Research, 2013, 51:21–24*

[6] Xingwei Han, Xue Dong, Qinli Song, Haitao Zhang, Jianyong Shi, Fulfillment of KHz SLR daylight tracking of Changchun Station, *Proc. Of 17th ILRS meeting, Fujiyoshida, Japan, November 11-15, 2013.*

[7] Tapley, Byron D. "Statistical orbit determination theory." *Recent Advances in Dynamical Astronomy. Springer Netherlands, 1973. 396-425.*

[8] Liu,L, Orbital Mechanics for Artificial Earth's Satellite, *Higher Education Press(in Chinese),1991.*

[9] McCarthy, Dennis D. "IERS technical note 21." *IERS Conventions 1996 (1996).*

[10] Vallado, David A., and Paul Crawford. "SGP4 orbit determination." *Proceedings of AIAA/AAS Astrodynamics Specialist Conference and Exhibit. 2008.*

Additional Information: Thanks to the support of National Natural Science Foundation of China 11303063.